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Impact of Resilience Strategies on Capital and Operational Expenditures

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Abstract

This paper studies the impact of resilience schemes on both the capital and the operational expenditures for a network operator. CapEx can be calculated from the network dimensioning. In order to determine the expected OpEx, we use a process-based approach. A case study is performed, considering a reference German 17-node network, based on WDM technology. The continuous cost of infrastructure (floorspace, energy, etc.) is an OpEx part which is directly influenced by the number of network components and therefore strongly linked to the network dimensioning and the CapEx. The routine operation and reparation processes are impacted by the dimensioning as well, because more equipment leads to more possible failures. On the other hand, the availability of backup capacity strongly reduces the time to get the network operational after the occurrence of a failure and therefore reduces these costs. Realistic figures are given for the case study and some more general trends are derived.

1 Introduction

In the past, several studies have been published indicating the impact of resilience strategies on network equipment costs, e.g. [1]. The impact on the operational expenditures, however, was neglected in most cases. This paper indicates a process-based approach to describe OpEx for a telecom operator. Apart from defining the process-based model, to goal of this paper is to clearly illustrate its use in a specific case study and to show how it can be complementary to common CapEx based studies. We will elaborate on the concrete input data and assumptions for all operational processes. This includes network equipment characteristics, failure statistics and estimated duration of some operational activities, needed in order to calculate labor costs. It is shown where the considered resilience scheme can impact the operator's OpEx. In the case study, we consider a reference German 17-node network, using WDM technology. Quantitative results on CapEx and OpEx costs are given, indicating the cost driving factors. Finally, some general thoughts about the CapEx/OpEx ratio are discussed.

2 Process based approach

We use the process-based OpEx cost model first described in [2]. It analyses the OpEx for an operational network, i.e. one that is up and running. We therefore don't consider the costs of the initial installation and those of network extensions.

All infrastructure is counted as CapEx in our model, as suggested in [3]. For an operational network, several OpEx categories can be distinguished. The general framework is defined by the continuous cost of infrastructure; what needs to be paid in any case to keep the network operational (also in the failure free case). It includes the costs of (floor) space, power and cooling energy. In principle, also leasing of network equipment and right-of-ways, i.e. the privilege to put fiber on the property of someone else (e.g. along railways) are part of this cost, but this is not considered in the quantitative study below. The continuous cost of infrastructure forms the general framework in which several operational processes can be distinguished, as illustrated in Fig 1.

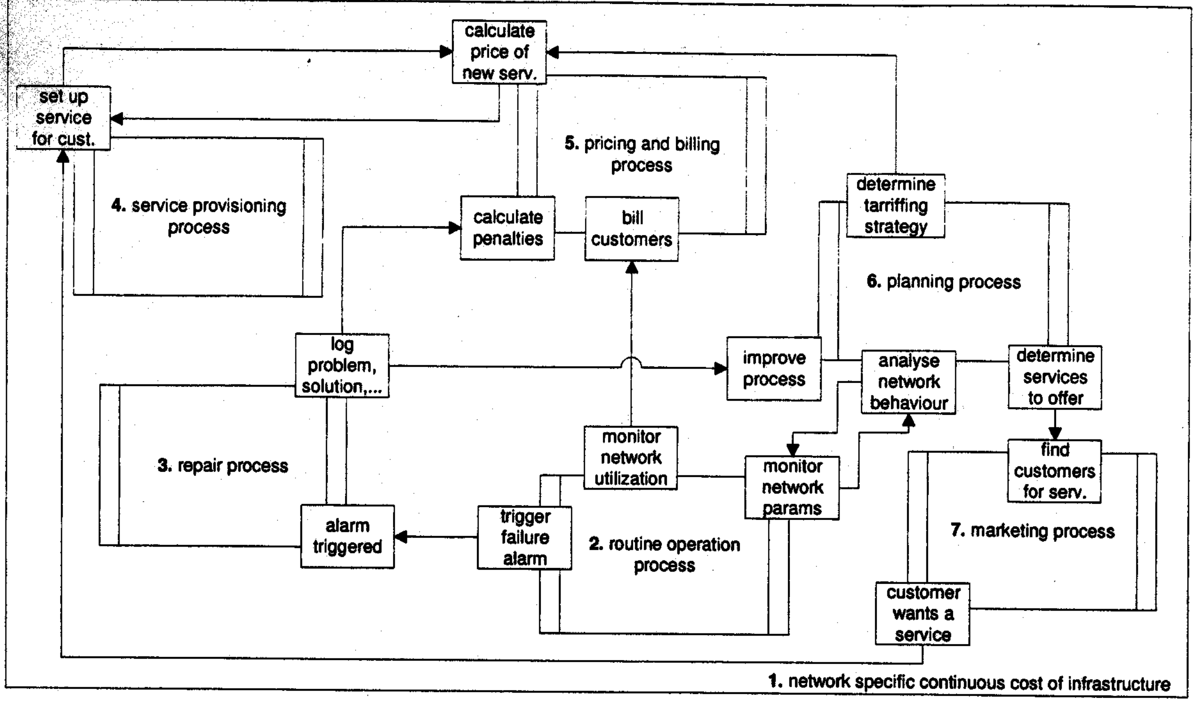


Fig 1 operational processes for network which is up and running

In practice failures can occur, so that monitoring the network's correct behavior becomes important. The routine operation process therefore becomes the central process. Several activities define its interaction with other processes. Network utilization info will serve as an input to the pricing and billing process. There is also a constant interaction between the planning process and the routine operation process. The first determines the parameters to be monitored by the latter and takes the monitoring results as an input to analyze the network behavior and suggest improvements for the future. In case of a failure alarm, the repair process is triggered. This process deals with actually repairing the failure in the network, if this cannot happen in routine operation. Reparation may lead to actual service interrupts, dependent on the used protection scheme. The actions involved in the reparation process are diagnosis and analysis, the technicians traveling to the place of the failure, the actual fixing of the failure and performing the necessary tests to verify that the failure is actually repaired. The service provisioning process is another central process which sets up the service requested by a customer. This means providing a (previously defined and negotiated) service to a customer. It follows after the service request by the potential customer and includes the entire process from order entrance by the administration till performing the needed tests. Also the actions in case a service is ceased should be counted here. This includes accepting the cessation request, deactivating the circuit, switching off and physically recovering the equipment. There is an interaction with the pricing and billing process to calculate the price of the provisioned service and another one with the repair process that indicates the downtime caused by a failure and therefore the potentially associated penalties to be paid to the customer. The marketing process can be seen as a side process trying to attract new customers, it therefore influences the service provisioning process. The actions involved are promoting a new service, provide information concerning pricing etc. The planning process interacts with all other processes as a steering process. It includes all planning performed in an existing network which is up and running, including day-to-day planning, re-optimization and planning upgrades.

In [2] all processes are described in a graphical way, with boxes indicating the actions and diamonds for questions indicating processes' branches. In this paper, we will attach costs to the actions and probabilities to the branches in order to perform some quantitative studies.

3 Assumptions and input data

In order to perform a quantitative study, a specific case needs to be selected. We study the optical layer of a national German network. Specific assumptions for network equipment characteristics, labour costs and failure probabilities are described in this section. Unless stated otherwise, the numbers are taken from [4].

equipment type	MTBF (h)	power (kW)	footprint (ETSI)	price (k€)
WDM line system (40 lambda)	2.00E+05	1	3 racks	12.00
fiber	7.00E+06	0	0	0.00
optical amplifier	2.00E+05	0.5	0.25 rack	7.90
SR transponder (2.5 Gbps)	3.00E+05	0.5	0 (inserted in OXC)	2.00
LR transponder (2.5 Gbps)	3.00E+05	0.5	0 (inserted in OXC)	2.50
unequipped OXC (512 ports)	1.00E+05	3	3 racks	100.00

Tab 1 network equipment characteristics

3.1 Network and equipment

We consider an optical (WDM) network, carrying 2.5 Gbps leased lines. Although, in a realistic network, leased lines would probably be offered via SDH or OTN over WDM, we focus on this leased-line-over-WDM architecture for the sake of having a very simple architectural model and focus on the expenditures modeling. The topology is the reference German network [5] with 17 nodes and 26 links and the associated traffic for 2004. The total and average link distances are 4427 and 170 km, respectively.

The characteristics of the considered network equipment are listed in Tab 2. We consider WDM line systems (mux/ demux, excluding transponders) with a potential of 40 lambdas, optical amplifiers are placed every 70 km, the transponders (both short reach as long reach) have a capacity of 2.5 Gbps. The optical cross connects (OXCs) allow transit traffic to bypass the intermediate nodes on the optical layer. The considered OXCs have 512 ports. We assume opaque OXCs, with identical characteristics for WDM transponders and OXC interface cards. For every equipment type, we indicate the expected failure rate (Mean Time Between Failures, MTBF) and energy consumption. Apart from the energy consumption to operate the equipment (power in Tab 1), we assume additional energy is needed for cooling this equipment. This is assumed to be 1/3 of the power indicated in Tab 1. The footprint of the equipment is expressed in ETSI racks (60*60cm). The component prices are determined from a combination of [6], [7], [8] and some own assumptions. Please note that those numbers indicate only rough estimations, without any reference to specific equipment. We assume that fiber is available anyway (dark fiber), so that we don't need to count a price for it.

Additional equipment cost assumptions are given in Tab 2. We consider a price of 0.08 Euro per kWh. Although prices may vary across several countries and for different customer categories, we consider this to be a realistic assumption [9]. As price for floor space rental we assume 10 Euro per square meter per month. Moreover, we assume the required free floor space (to allow the technician to configure and replace equipment) to be a bit bigger than the floor space taken by the equipment itself, expressed by the floor space correction factor of 2.5. Note that this value can, to some extent, also be determined by the maximum allowed load per square meter. Finally, the equipment life time is set to 10 years. In order to be able to calculate the yearly capital equipment costs, the total equipment costs are divided by this equipment life time.

Parameter	Value
price per kWh	0.08 euro
price floor space rental per m^2 / month	10 euro
correction factor for floor space	2.5
Equipment life time	10 years

Tab 2 additional equipment cost assumptions

3.2 Operational activities

The description of the operational processes involves several actions/activities that need to be performed by the operator's personnel. The duration of the activity determines, to an important extent, the cost of the action. Tab 3 summarizes the actions in the routine operation and reparation process with their expected duration. Several phases are distinguished. The activities of the helpdesk people include helpdesk calls and customer notification. The time for diagnosis and isolation depends on the type of the failure. The costs for transport (going to the location of the failure) are calculated from the topology characteristics. We assume that technical teams are present on average 2 links away from one another, this is every 340 km. The average distance to the failure location is therefore 85 km. One way and return adds to 170 km, with an average speed of 50 km/h, this means 3.4 hours for transport. The actual time for reparation again depends on the type of failure and the test consists of a component test to be performed by a technician on site and an end-to-end test, to be performed from the NOC.

In addition to the activities in Tab 3, some rather continuous actions are also included in routine operation. We assume 1 person year for monitoring and 0.5 person year for access and data integrity control.

action		duration (hours)
helpdesk	customer reporting problem	1
	notify customer notification on expected problem	0.5
	notify customer on problem solution	0.5
	create trouble ticket	1
diagnosis & isolating	network fault diagnosis	0.5
	isolating fault at CPE	1
	isolating internal fault	1
	finding cable cut location and isolating it	2
transport	going to location of failure	3.4
reparation	preventive replacement	0.2
	repairing and testing at CPE	1
	repairing problem from NOC	0.5
	repairing HW or replacing and reconfiguring	1
	fixing cable	4
test	component test	1
	e2e test	0.5

Tab 3 activities in routine operation and repair process

Action		duration (hours)
pricing and billing	get price from coverage map	0.5
	calculate penalty	0.5
	assign cost to customer account	0.5
	distribute bill	0.2
	check payment	1
service provisioning	contract handling and administration	1
	create work packages	2.5
	plan, install, configure local domain	0.5
	plan, install, configure external	1
	progress information to customer	0.2
	customer care delivery report	0.5
marketing	time to handle a service request (sales)	4
planning	planning time	1

Tab 4 activities in pricing and billing, service provisioning, marketing and operational planning

The activities for the other operational processes are listed in Tab 4. Pricing and billing involves calculating the price of the requested service. As we only consider standard leased line services here, this means getting the price from the coverage map. Furthermore, assigning costs to the customer accounts also includes calculating penalties if needed (in case of service interrupt). Please note that the costs to pay the penalties themselves (which is also an operational cost for the operator) are not considered here. In general, also the costs to trace bad payers should be included. In this study, however, we consider business customers and not the mass market, so that we assume tracing bad payers can be neglected here. The activities for service provisioning are a simplified version of [11]. We consider service delivery, while neglecting service cessation. We differ between the costs for planning, installation and configuring in the local domain and externally and assume that the probability for a problem in the internal domain is 1.5 times as big as that for an external problem. The costs/durations for service provisioning indicate the time needed to provision a single connection. Note, as will be explained below, that in case of 1+1 protection actually 2 connections need to be set up. Therefore, in this case, the number given here need to multiplied by 2. The marketing and operational planning processes are modeled in a straightforward way, only including one activity. One hour for planning per leased line, is assumed for the unprotected case. In case of shared path or 1+1 protection, we believe this time to double to 2 hours.

2.3 Personnel

The costs of a certain operational activity can be calculated by its duration (from the tables above) multiplied by the hourly cost of the employee performing this activity. We distinguish several personnel categories: sales, technical field personnel, technical personnel in the NOC, administrative and helpdesk personnel, researchers and engineers. Personnel cost information is given in Tab 5. The overhead indicates a factor with which the salary needs to be multiplied in order to find the fully accounted cost of this person for the company. Apart for the wages and the taxes, this also includes additional costs such as tools and transport, see also [2]. Exactly calculating the amount of training and the tools needed for each of the considered actions is probably impossible. But the overhead factor allows to indicate the general trends. There will be more training needed for personnel performing difficult technical tasks than for people answering help desk calls. Technicians also need more tools than administrative personnel. The use of the overhead factor is based on a suggestion by [10]. To calculate an hourly cost from a yearly cost, we assume 38 working hours in a week and 46 weeks a year, taking into account holidays.

department	salary, incl. taxes (euro/year)	overhead factor	fully accounted cost (euro/hour)
sales	90000	3	154
technical	78300	3	134
NOC	64800	2	74
administration, helpdesk	72000	2	82
research, engineering	81000	2	93

Tab 5 personnel cost

2.4 Failure probabilities

We assume two types of alarms in the network: preventive alarms and failure alarms. Based on the observation of [12] that 39% of all outages longer than 2 min were scheduled, we assume 39% of all alarms to be preventive alarms. Considering failure alarms, we observe several problem causes: CPE problems, external problems (power disruptions, ...), misconfigurations or software failures and hardware failures incl. cable cuts. The probabilties of these problem causes are specific for an optical network [4]. For higher network layers (SDH or IP) the probability for a configuration or software failure is much higher. The considered failure probabilities are listed in Tab 6.

Based on the MTBF information of Tab 1, the total number of hardware failure in one year over the entire network was determined to be 925. With the ratios of Tab 6, this adds to a total of 1171 failure alarms and 749 preventive alarms per year.

alarm type	probability		
preventive	39%		
failure	61%	CPE problem	3%
		external problem	4%
		misconfiguration/ SW problem	14%
		HW problem (incl. cable cut)	79%

Tab 6 failure probabilities

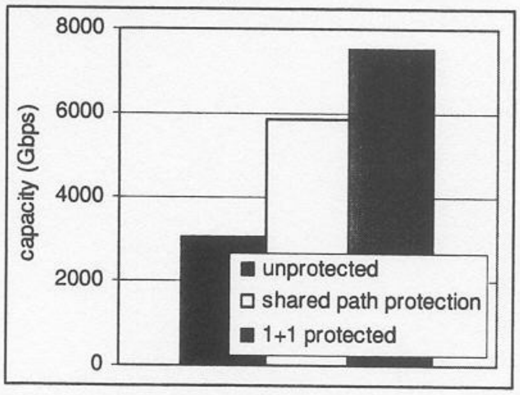
2.5 Customer and contract information

The final category of relevant data to calculate the expected OpEx concerns the customers and their contracts.

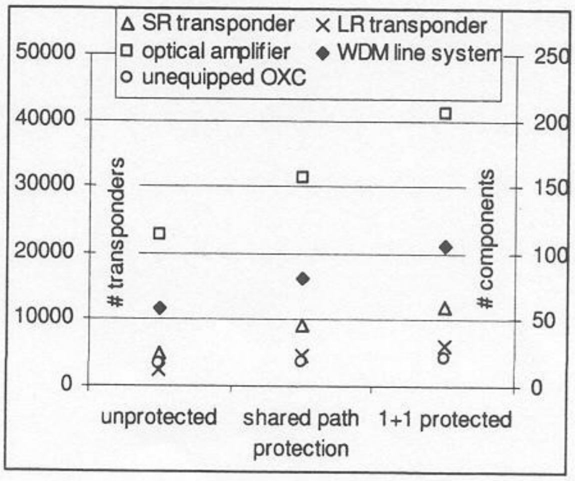
We consider an (optical) backbone network, therefore the customers are probably no end users, but rather business customers (companies). The number of actual leased lines is estimated as 1214. This is a rough estimation, obtained by dividing the total traffic of 3035 Gbps by the leased line capacity 2.5 Gbps). As we are dealing with business customers, we assume all of them to have business contracts including notification on expected problems and on the solution of a problem. None of the considered contracts include customers support. Furthermore, we believe the network monitoring to work well, so that all problems are apparent from that. Helpdesk calls only report known problems. We assume 1.5 helpdesk call per network problem, as a problem is probably noticed by more than one customer.

4 Impact of resilience scheme

We consider three different resilience schemes. In case of an *unprotected network*, there is no protection against failures. The advantage of this way of working is the absence of overdimensioning. The dimensioning results are shown in Fig 2. A small dimensioning has a positive impact on CapEx (equipment itself) as well as OpEx (in terms of energy, floor space to operate this equipment). When a failure occurs, a new path needs to be calculated and set up.



(a) dimensioning in terns of capacity



(b) dimensioning in terms of network equipment

Fig 2 dimensioning results

We assume path calculation to be done by an online tool in all cases, so that it doesn't generate any cost. In case of an unprotected network, the configuration happens manually, which can take quite some time. We assume 8 hours in Tab 7. During this time, the network will be unavailable, so that probably penalty costs need to be paid. Note that those penalties are not considered further in this study, which also explains why we don't consider outage times, but rather recovery times (time till the network recovers from some failure). Note that probably not all capacity can be restored because the unprotected network was not dimensioned to allow restoration, but this is not taken into account here. Also re-rerouting was not considered.

Shared path protection allows to share backup capacity between several backup paths. The end-to-end backup paths are precalculated, but not set up beforehand. In case of a failure, the path is set up automatically. We assume this to take 0.05 hours (= 3 minutes), instead of 8 hours in the unprotected network. In case of a double failure, the backup path might already be occupied, so that it should be restored like an unprotected connection then. In this study only single failures are assumed.

In case of *1+1 path protection*, a backup path is predetermined and set up for each working connection. The backup capacity is dedicated to a certain backup path, which leads to more required capacity and therefore higher expenses in CapEx and OpEx. On the other hand, the cost to reroute the traffic becomes neglectable (0 instead of 8 hours), as the traffic is sent over the backup path all the time. 1+1 path protection has an impact on the service provisioning cost as well. Indeed, when setting up a connection, we always need to set up both the working and the backup path. The cost of setting up a connection is therefore twice as big as in the other cases.

resilience scheme	time to reroute traffic (h)
unprotected	8
1+1 protection	0
shared path protection	0.05

Tab 7 impact of resilience scheme on time to reroute traffic

5 Quantitative results

5.1 Capital expenditures

The first step in order to determine required CapEx and OpEx for the considered network and traffic, is to dimension the network, see the results of Fig 2. Taking into account the equipment costs and the expected life time, this allows to calculate the yearly CapEx costs for the different resilience schemes, see Fig 3. It is clear that the main difference is coming from the different amounts of transponders (line capacity) needed for the different resilience schemes. As an unprotected network has no overdimensioning, opposed to the other considered schemes, the CapEx cost for this scheme is the smallest. The total CapEx cost for the shared path protected case is 81% bigger than in the unprotected case (mainly coming from the transponder cost which is 93% bigger). The total CapEx for the 1+1 protected network is 131% bigger than that for the unprotected one (148% when only considering transponders).

5.2 Operational expenditures

Concerning operational expenditures, the results are shown in Fig 4. The continuous cost of infrastructure follows more or less the same trends as the CapEx costs. In case of shared path protection it is 164% of that for the unprotected network, in case of a 1+1 protected network it is 209%. The continuous cost of infrastructure is composed of two parts: energy consumption and floor space rental. With the assumptions made here, the cost for energy consumption is in the same order of magnitude as that for floor space rental. The continuous cost of infrastructure constitutes more than half of the total OpEx cost: 56% in case of an unprotected network, 75% for shared path protection and 78% in case of 1+1 protection. The remainder of the OpEx is constituted by the process based costs. In this respect, we need to point out that our study only considered the OpEx costs for a network which is up and running. Also counting the operational expenses for first-time installation in the process-based costs probably would have changed the picture.

Having a closer look at the process based OpEx (network which is up and running), we notice that reparation is more expensive (almost twice as expensive) in case of an unprotected network, because of the additional effort to reroute the traffic in case of a failure. The cost for service provisioning is more than 1.5 time bigger in case of 1+1 protection than in the other cases, because the first approach requires to setup almost twice as many connections as the others cases. The costs for planning are smaller (half) for the unprotected network, because backup scenarios do not need to be planned for. Taking all processes together, the overall process based OpEx is cheapest in case of shared path protection, it is 10% bigger for 1+1 protection and even 24% bigger in case of an unprotected network.

When combing network specific continuous infrastructure costs with process based OpEx, we see that the cheapest solution in terms of OpEx is given by the unprotected network. A network using shared path protection is 30% more expensive to operate, a network offering 1+1 protection even 60%.

5.3 Overall costs

Bringing together the results of the two previous sections leads to the results of Fig 5. It is clear that, with the considered assumptions, CapEx exceeds OpEx costs in all case. The ratio OpEx/CapEx is 60% for an unprotected network, 43% for shared path protection and 42% for 1+1 protection. We remind the reader again that the operational expenses for first-time installation as well as the general expenses for non-telco specific administration and infrastructure are not counted. This can explain why we find that OpEx is smaller, on a yearly basis, than CapEx. However, we see significant differences between the resilience schemes under identical assumptions which may be interpreted as general trends for their influence on OpEx.

6 Conclusions and future work

In this paper, we have considered CapEx and OpEx costs for a backbone transport network and studied the impact of different resilience schemes on those costs. The first, obvious impact of the considered resilience scheme was observed in the dimensioning results. This has a direct effect on the CapEx costs and the OpEx part which is directly related to continuous costs of infrastructure (floorspace, energy,...). Those costs are smallest for the unprotected network and grow with the needed required amount of backup capacity. A similar trend was seen for the costs of service provisioning, which is most expensive in case of 1+1 protection (more connections need to be set up). Also planning costs grow with the amount and complexity of failure scenarios that need to be planned for. Finally, also the reparation process is impacted by the dimensioning, because more equipment leads to more possible failures. On the other hand, the availability of backup capacity strongly reduces the time to get the network operational after the occurrence of a failure and therefore reduces this cost. Considering the overall picture, CapEx exceeds OpEx costs in all cases, but we note significant differences between the resilience schemes. The network using shared path protection is the cheapest to operate.

This paper reports preliminary results. Future work will focus on improving and validating the model. The estimations for the input data will be improved, by further questioning network operators. The OpEx and CapEx cost results obtained by the model will be compared to real expenses as described in telecom operators' year reports. The final goal of this work will be to come up with a useful decision support tool, which allows network operators to take OpEx costs into account in a straightforward way in their network evaluation studies.

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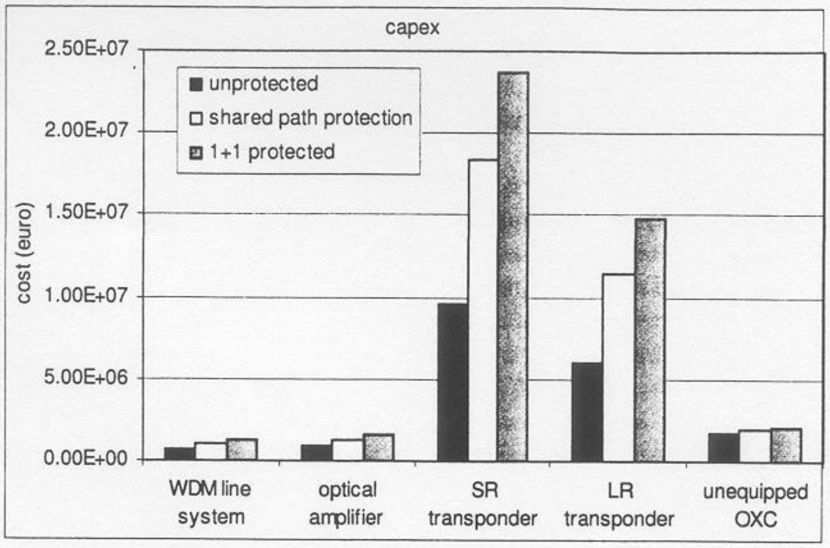

Fig 3 Impact of resilience schemes on CapEx

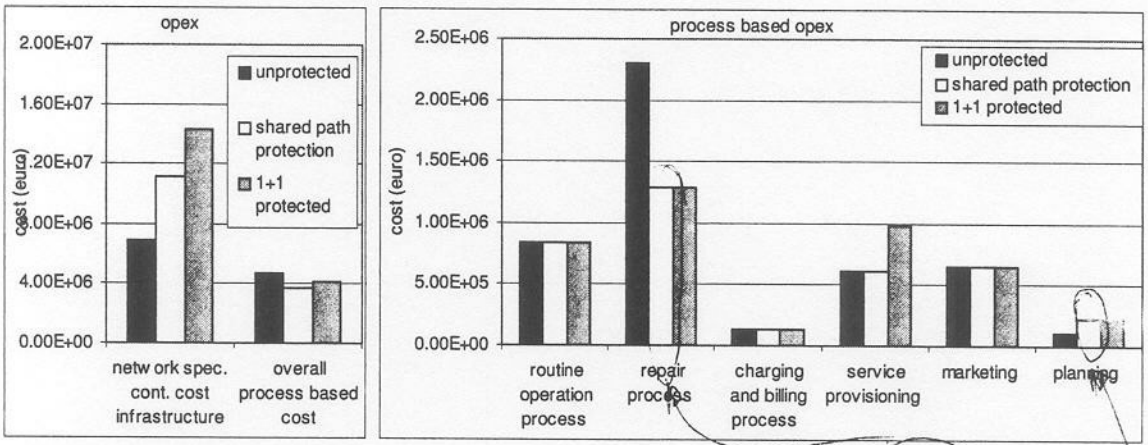

Fig 4 Impact of resilience schemes on OpEx

shared path is more work

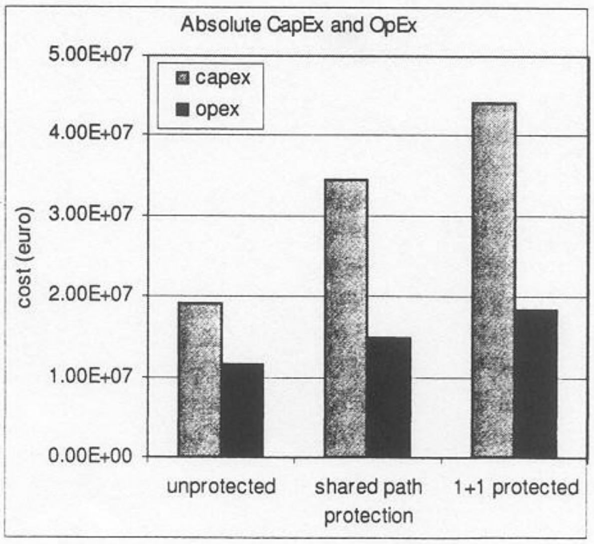

Fig 5 Impact of resilience schemes on overall costs

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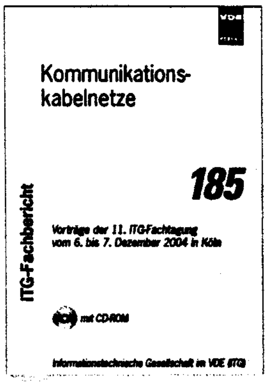

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